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## AN EXPERIMENTAL STUDY OF SOUND RADIATION FROM HYPERBOLOIDAL INLET DUCTS

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16 Abstract This report presents an experimental study of sound radiation from hyper- bolloidal inlet ducts which include a circular cylinder with plane baffle as a limiting case. Results include the polar angle variation of the pressure level and the phase of the radiated field for various frequencies and various modes incident which were produced using an electronically operated mode synthesizer. The results are in generally good agreement with a rigorous theoretical prediction.					
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# AN EXPERIMENTAL STUDY OF SOUND RADIATION FROM HYPERBOLOIDAL INLET DUCTS

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## SUMMARY

Results are presented from an experimental study of sound radiation from hyperboloidal inlet ducts which was conducted using a mode synthesizer as the sound source. The pressure level and the phase of the radiated sound field were measured as functions of polar angle for various hyperboloidal inlets, incident wave modes, and frequencies. The results are conclusive and are in good agreement with predictions which were made by means of a recently developed theory of the sound radiation from hyperboloidal inlet ducts.

## INTRODUCTION

The advent of jet-powered commercial transport aircraft has created considerable interest in sound radiated from the fan ducts of the engines used. The noise field generated in such ducts is often composed of higher order duct modes. In fact, the generation of the axisymmetric modes including the fundamental mode is negligible in a "typical" turbofan duct. It is therefore imperative to examine the radiation of higher order (spinning) modes in some depth in order to understand noise radiation characteristics of such a fan duct. Such studies are directly related to the overall control of aircraft noise.

This paper presents sound radiation patterns measured with various hyperboloidal inlet ducts. The experimental data are compared with theoretical

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results taken from an analysis by Y. C. Cho described in reference 1. This reference describes the sound radiation characteristics of hyperboloidal inlets in detail.

One reason for testing these particular inlets is that rigorous solutions are available for the problem of sound radiating from them. The primary objective of this study is to provide experimental verification of the radiation theory given in reference 1. This study is part of a NASA Langley research program undertaken to advance the understanding of sound radiated by various inlet duct configurations.

The acoustic measurements presented in this paper were made in an anechoic chamber at the Langley Research Center, Acoustic and Noise Reduction Laboratory utilizing a spinning mode synthesizer as a noise source in a duct. Data include the angle dependent pressure level and phase of the sound field associated with various essentially single incident modes over various frequency ranges (see Table I).

The following sections contain discussions of test apparatus and procedure, results, and conclusions.

## TEST APPARATUS AND PROCEDURE

### Sound Source

The sound radiation study was conducted in an anechoic chamber measuring 6.07 m wide by 9.09 m long by 7.29 m high. The sound source is a spinning mode synthesizer (SMS) that consists of a source section (0.30 m inner dia.) with a series of circular ducts secured to each of its ends. The ducts at the upstream end of the source section are installed in one wall of the anechoic chamber as shown in figure 1. The synthesizer is controlled with a

computer to generate one or more spinning mode patterns at arbitrary discrete frequencies. By regulating the phases and amplitudes of 24 acoustic drivers positioned around the source section and mounted flush with its inner wall, specific modes are produced inside the duct. The resulting noise field is monitored by an array of microphones located a short distance upstream of the drivers. These microphones are flush with the inner wall of the source section and are arranged circumferentially at the same location. The acoustic pressure measured at these microphones is operated on by the computer to generate correction signals to the drivers in order to adjust the noise field to within a known degree of error.

#### Inlet Ducts

Three configurations as shown in figures 2 and 3, a 50° hyperboloidal inlet, a 70° hyperboloidal inlet, and a cylinder with plane baffle were used in this study. The former inlets are made of fiberglass, and the latter inlet consists of a short aluminum duct with a plywood plate mounted on it. Wooden braces are fastened to the baffle in order to keep it flat and free of vibrations during data acquisition. The 50° hyperboloidal inlet has an inner diameter of 2.44 m at the entrance plane and a length of 1.09 m. The 70° hyperboloidal inlet has an inner diameter of 2.46 m at the entrance plane and a length of 0.51 m. The baffled cylinder is configured with an overall baffle diameter of 2.44 m and a length of 0.46 m. Each inlet duct has an exit diameter of 0.30 m. Figure 3(a) shows the 50° and 70° hyperboloidal inlets outside the anechoic chamber. Figure 3(b) shows the baffled cylinder inside the anechoic chamber as it was mounted on the synthesizer for testing. The centerline of the inlet is 2.74 m from the top of the wedges on the chamber floor.

## Instrumentation

Sound radiation patterns were measured in front of each inlet configuration using a 1.27 cm diameter condenser microphone mounted on a traversable boom as shown in figure 3(b). The microphone was set at the same elevation as the duct centerline and with its diaphragm in the vertical plane ( $0^\circ$  incidence). Design of the boom was such that the boom radius (the distance between the microphone diaphragm and the plane at  $z = 0$ ) could be easily varied. The boom, which was motorized, was controlled by computer. A variable frequency pistonphone calibrator was used to calibrate the boom microphone at the beginning and end of each test day.

## Procedure

Using a computer terminal located in a control room adjacent to the anechoic chamber, the computer was instructed to set up various spinning modes over a range of frequencies. Table I gives the modes and frequencies for which data were obtained in this study.

Following each mode setup the boom microphone was traversed from  $-45^\circ$  to  $+45^\circ$  on a 1.37 m radius in front of the  $50^\circ$  hyperboloidal inlet. The  $70^\circ$  hyperboloidal inlet was tested with a boom radius of 1.12 m on an arc from  $-65^\circ$  to  $+65^\circ$ . A radius of 0.91 m was used to sweep the boom from  $-85^\circ$  to  $+85^\circ$  in front of the baffled cylinder. The boom microphone was rotated at an angular speed of 1 deg/sec for each inlet.

The sound radiation data were recorded on disc and could be recalled and plotted by the computer at a later time. Anechoic chamber temperature and relative humidity were also obtained, but these were printed by the computer on line.

## RESULTS AND DISCUSSION

A complete list of the test cases used in this study, each of which is a combination of inlet, frequency, and incident wave mode, is given in Table I. For each case, the result obtained in terms of radiation directivity has been compared with the theoretical calculation made in accordance with equation 31 in reference 1. As indicated in the table, the theory and the measurement have been found in good agreement in most cases. Good agreement was considered to exist for those comparisons where the measured and predicted sound pressures differed by no more than 2 dB to 3 dB at the azimuthal angles of interest. Agreement between the measured and predicted phase data was considered good if differences no greater than  $10^\circ$  were observed at the angles of interest.

The discrepancy between the theory and the measurement, which was found in some cases, may be attributed to the fact that more than one mode was generated in the duct by the mode synthesizer. In each case, however, the desired mode was isolated from the undesirable ones by at least 15 dB to 20 dB. Interference of the modes results in complicated sound radiation patterns, but radiation of multimode incident waves will not be discussed further in this report.

Experimental results are presented in figures 4 to 7 for several test cases. The sound pressure level and the phase of the radiated field are plotted therein as functions of polar angle. Also shown in the figures is the theoretical prediction.

In figures 4(a) and 4(b) the pressure level and the phase of the radiated field associated with the baffled cylinder are displayed, respectively, for the (0,0) mode incident and the frequency 1008 Hz. The agreement between

the measured and predicted data is quite good in each of these figures. This is not unexpected, however, since interference from undesirable modes was not a major problem at low source frequencies. Displayed in figure 5 is the pressure level of the radiated field from the same inlet duct for the (8,0) mode incident and the frequency 4256 Hz. In this figure the measured and predicted sound pressure level data are in good agreement at polar angles below  $-30^\circ$  and above  $30^\circ$ . The lack of agreement between the curves inside these two angles, and at this relatively high frequency, is due in part to the presence of unwanted modes and in part to the concentration of most of the acoustic energy at the higher angles of sound radiation. Another factor suspected of adversely affecting the data comparison is the limited dynamic range of the sound measuring system. The phase measurement is not presented in this case because of its inaccuracy. It is, in general, difficult to make a reliable measurement of the phase of a high frequency field. Furthermore, the phase information becomes less useful as the frequency increases.

In figures 6(a) and 6(b) the pressure level and the phase of the sound field in front of the  $70^\circ$  hyperboloidal inlet are plotted, respectively, for the (1,0) mode incident and the frequency 960 Hz. Generally, the comparison of measured and predicted data in these figures gives good agreement except for discrepancies in phase at small polar angles. The agreement exhibited by the data may be attributed to the relatively good mode setup associated with the low source frequency. The disagreement between the phase measurement and the theory that occurs at small polar angles in this case is of no significance, since the pressure level for such angles is negligibly small compared with the highest pressure levels of the radiated sound pattern.

In figure 7 the pressure level radiated from the  $50^\circ$  hyperboloidal inlet is plotted for the (6,0) mode incident and the frequency 3312 Hz. Good agreement generally occurs between the measured and predicted curves except at the smaller radiation angles ( $-18^\circ$  to  $20^\circ$ ). The lack of agreement in sound pressure at these intermediate angles is mainly due to generation of axisymmetric modes which result in some contamination of the (6,0) mode. Phase data are not included in this figure because of difficulty in measuring it accurately at 3312 Hz.

#### CONCLUDING REMARKS

The experimental results and the theoretical predictions compared in this study have been found to be in good agreement, in spite of the difficulty in setting up pure spinning-mode source patterns. In conclusion, then, the results provide a reasonable experimental verification of the radiation theory documented in reference 1.

#### ACKNOWLEDGEMENTS

The authors wish to express their appreciation for assistance with data acquisition rendered by Richard J. Silcox and discussions with Jean-Michel Ville on data analysis.

#### REFERENCE

1. Cho, Y. C.: Sound Radiation from Hyperboloidal Inlet Ducts. AIAA Paper No. 79-0677, March 1979.

TABLE I.- CASES TESTED IN SOUND RADIATION STUDY<sup>(A)</sup>

CASE NO.	INCIDENT WAVE MODE	FREQUENCY, HZ	HYPERBOLOIDAL INLET ANGLE		
			50°	70°	90° <sup>(B)</sup>
1	(0,0)	502	-	-	✓
2		1008	-	-	✓
3		1359	-	-	✓
4		1912	-	-	x
5	(1,0)	689	✓	✓	✓
6		734	✓	✓	✓
7		815	✓	✓	✓
8		960	✓	✓	✓
9		1990	x	x	x
10	(2,0)	1143	x	x	x
11		1218	✓	✓	✓
12		1348	✓	✓	✓
13		1591	✓	✓	✓
14	(4,0)	1990	x	x	x
15		2122	✓	✓	✓
16		2346	x	x	x
17	(6,0)	2807	x	x	x
18		2994	✓	✓	✓
19		3312	✓	✓	✓
20		3907	✓	✓	✓
21	(8,0)	3650	x	x	x
22		4256	✓	✓	✓

(A)

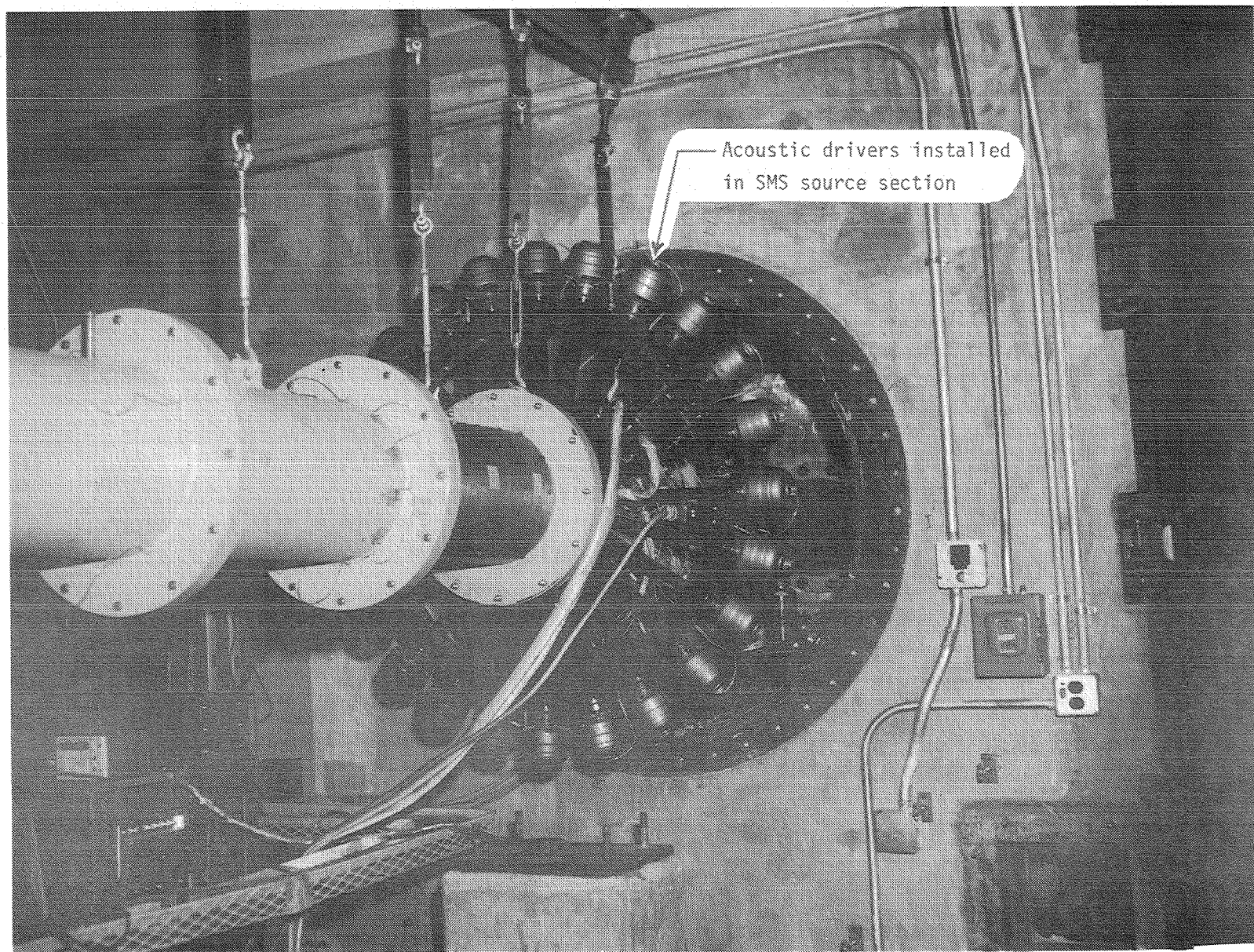
- INDICATES NO TEST PERFORMED

✓ GOOD AGREEMENT BETWEEN MEASUREMENT AND PREDICTION

x POOR AGREEMENT BETWEEN MEASUREMENT AND PREDICTION

(B)

90° HYPERBOLOIDAL INLET DUCT SAME AS CIRCULAR CYLINDER  
WITH PLANE BAFFLE



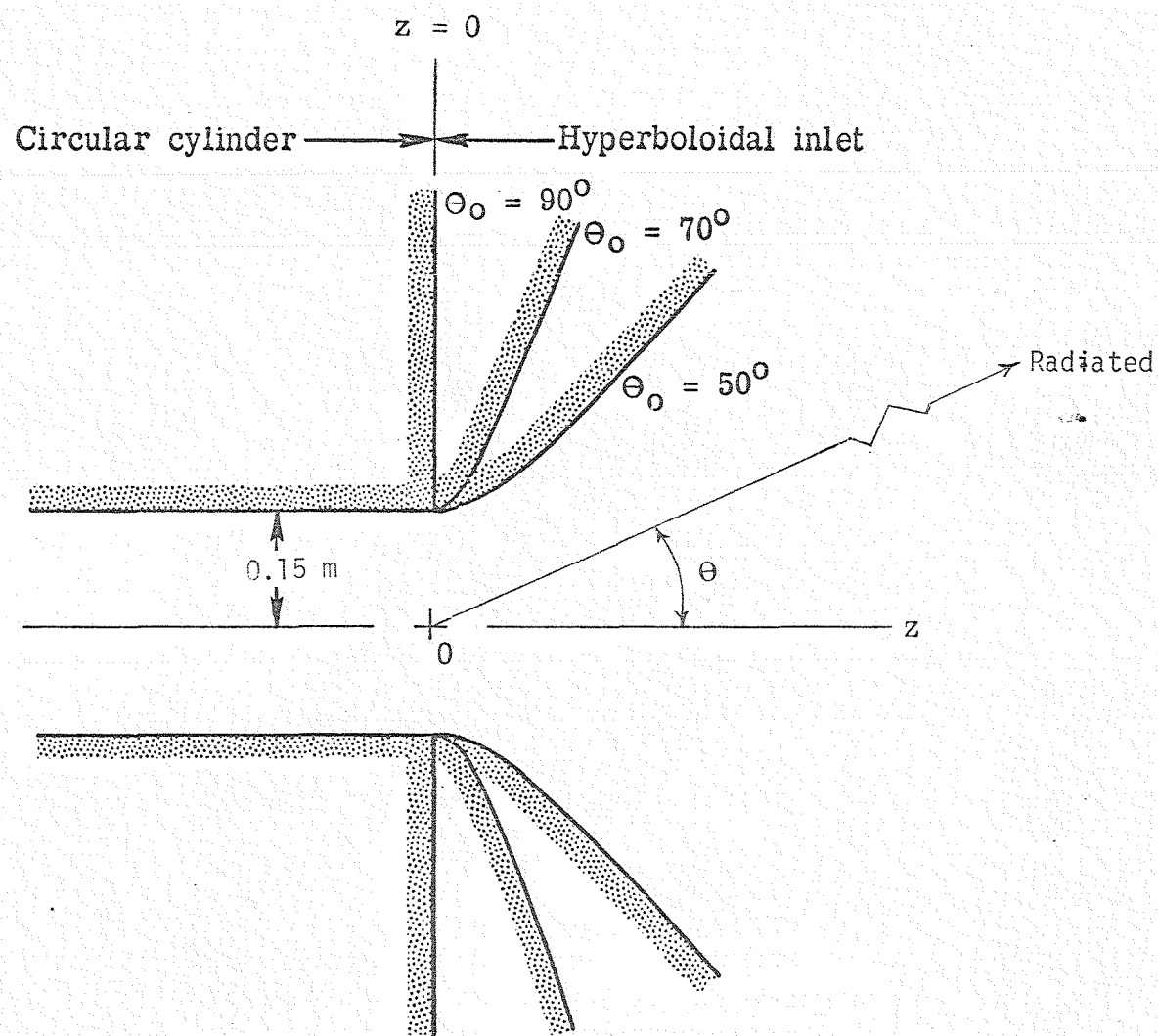
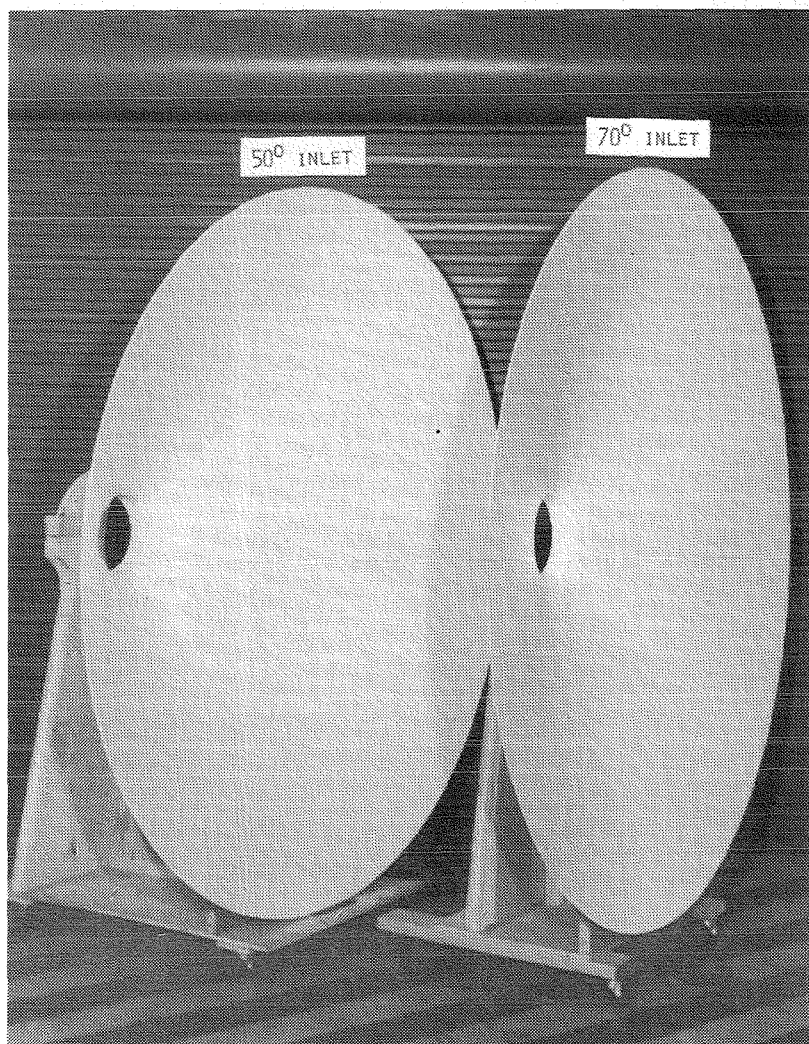
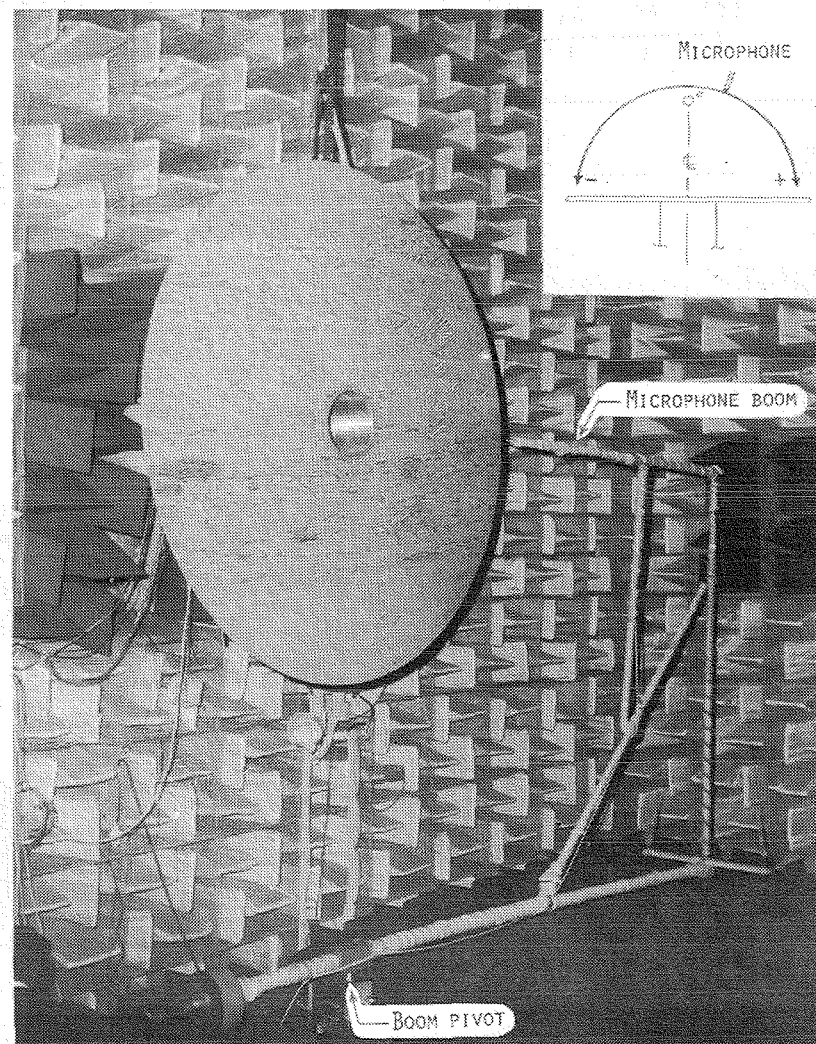


Figure 2.- Hyperboloidal inlet ducts of inlet angles  $50^\circ$ ,  $70^\circ$ , and  $90^\circ$

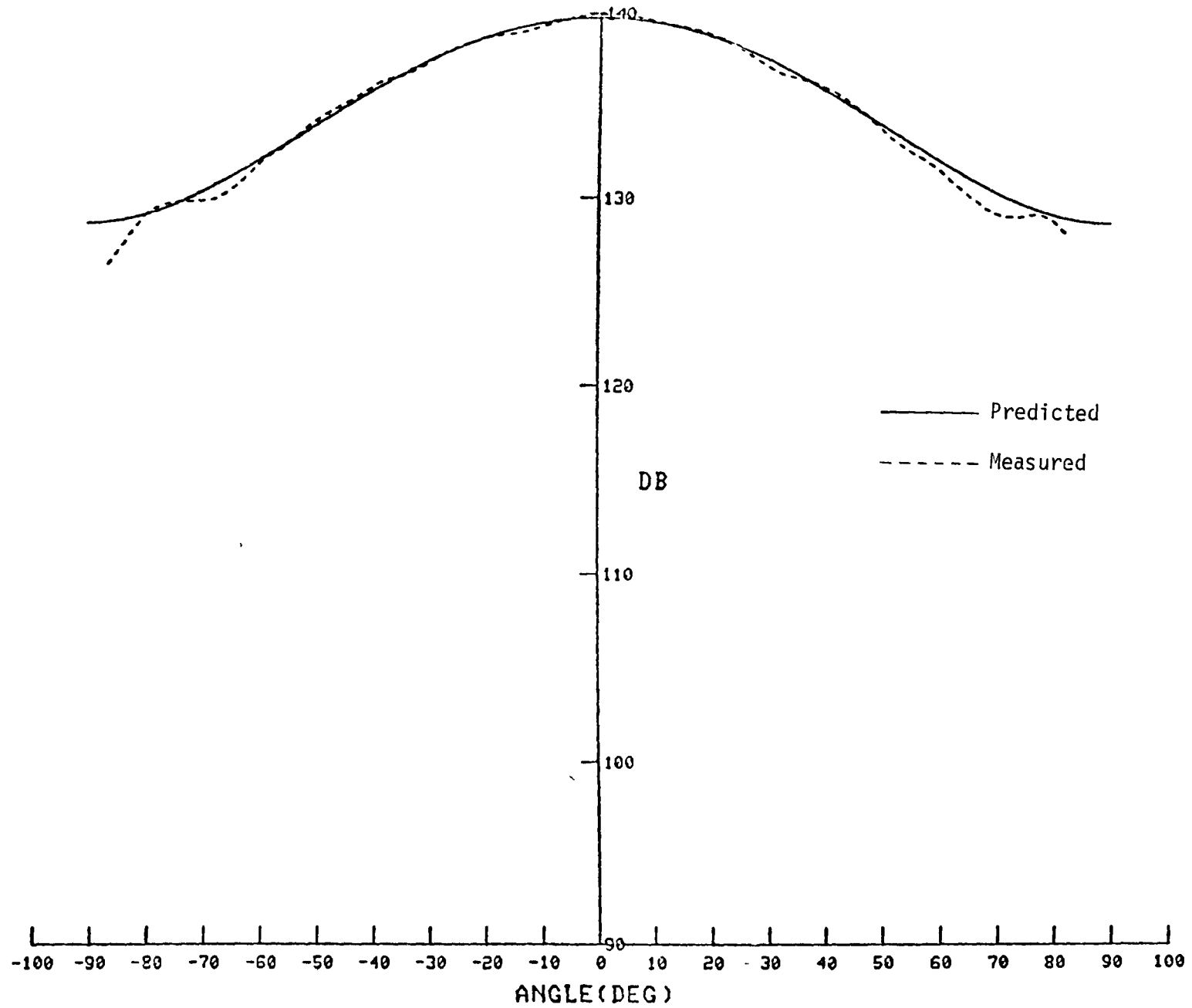


(a)  $50^\circ$  and  $70^\circ$  HYPERBOLOIDAL INLETS OUTSIDE ANECHOIC CHAMBER



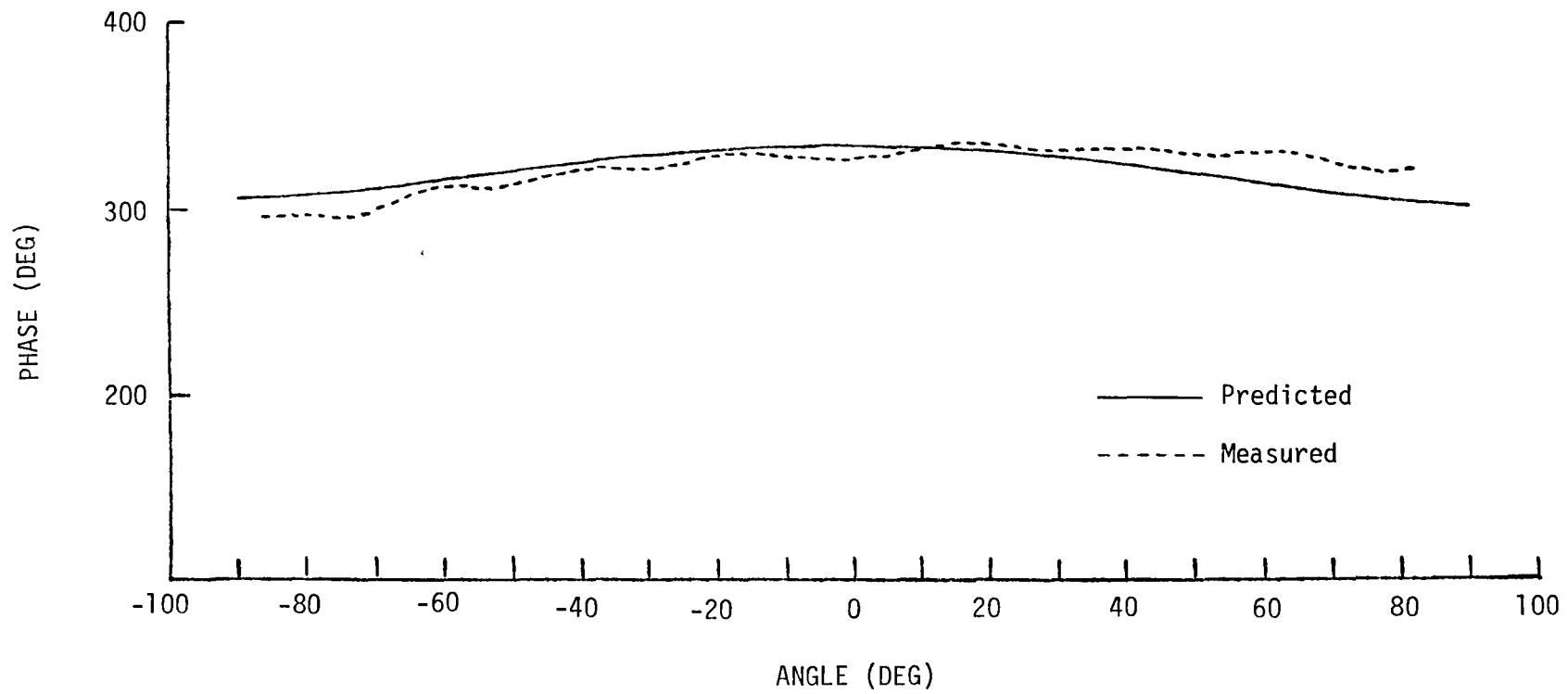
(b) CIRCULAR DUCT WITH PLANE BAFFLE INSIDE ANECHOIC CHAMBER

FIGURE 3.- PHOTOGRAPHS OF INLET DUCT CONFIGURATIONS



(a) Pressure level of radiated field

Figure 4.- Sound pressure level and phase of radiated field from circular cylinder with plane baffle versus polar angle for (0,0) mode incident and frequency 1008 Hz



(b) Phase of radiated field

Figure 4.- Concluded

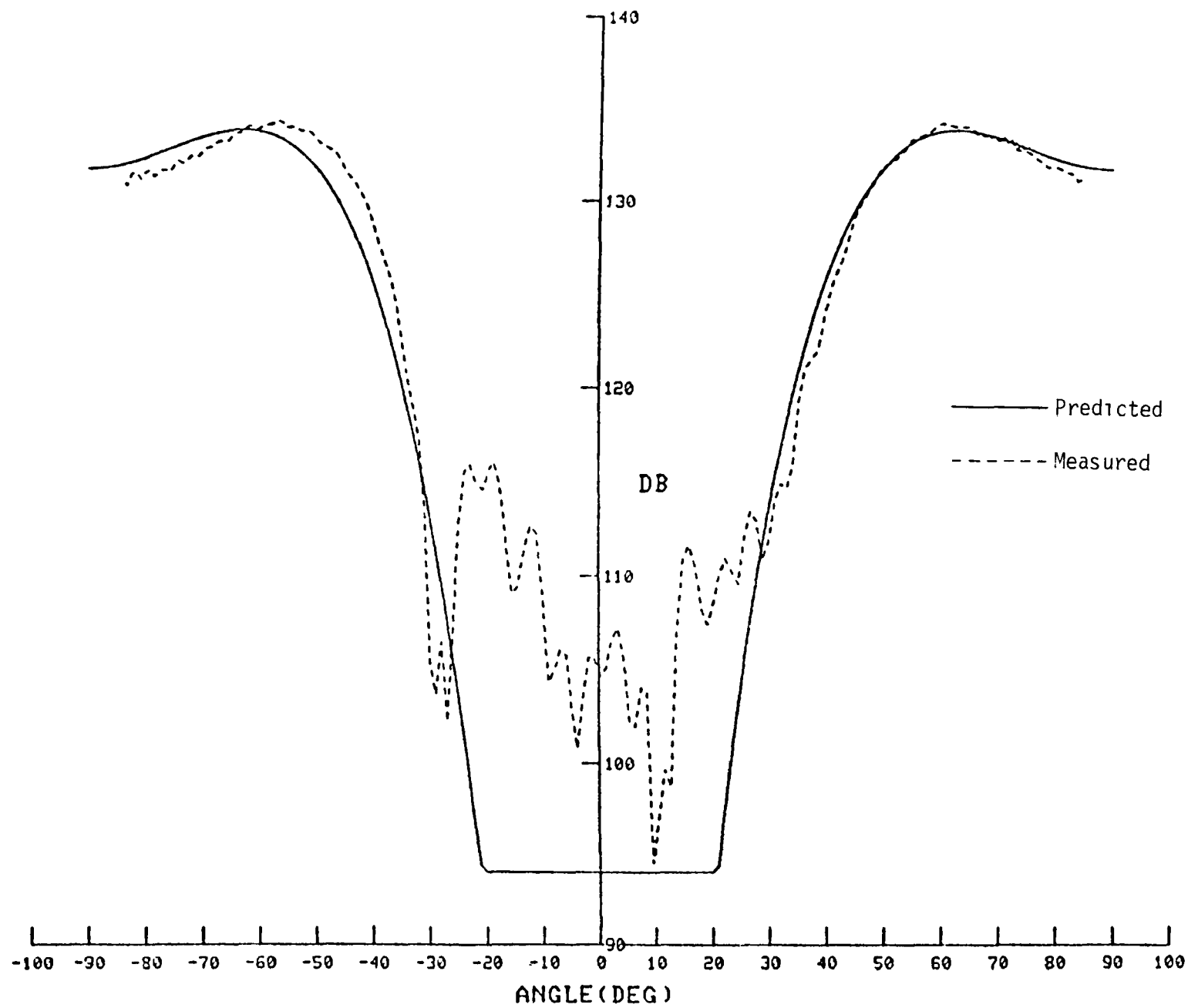
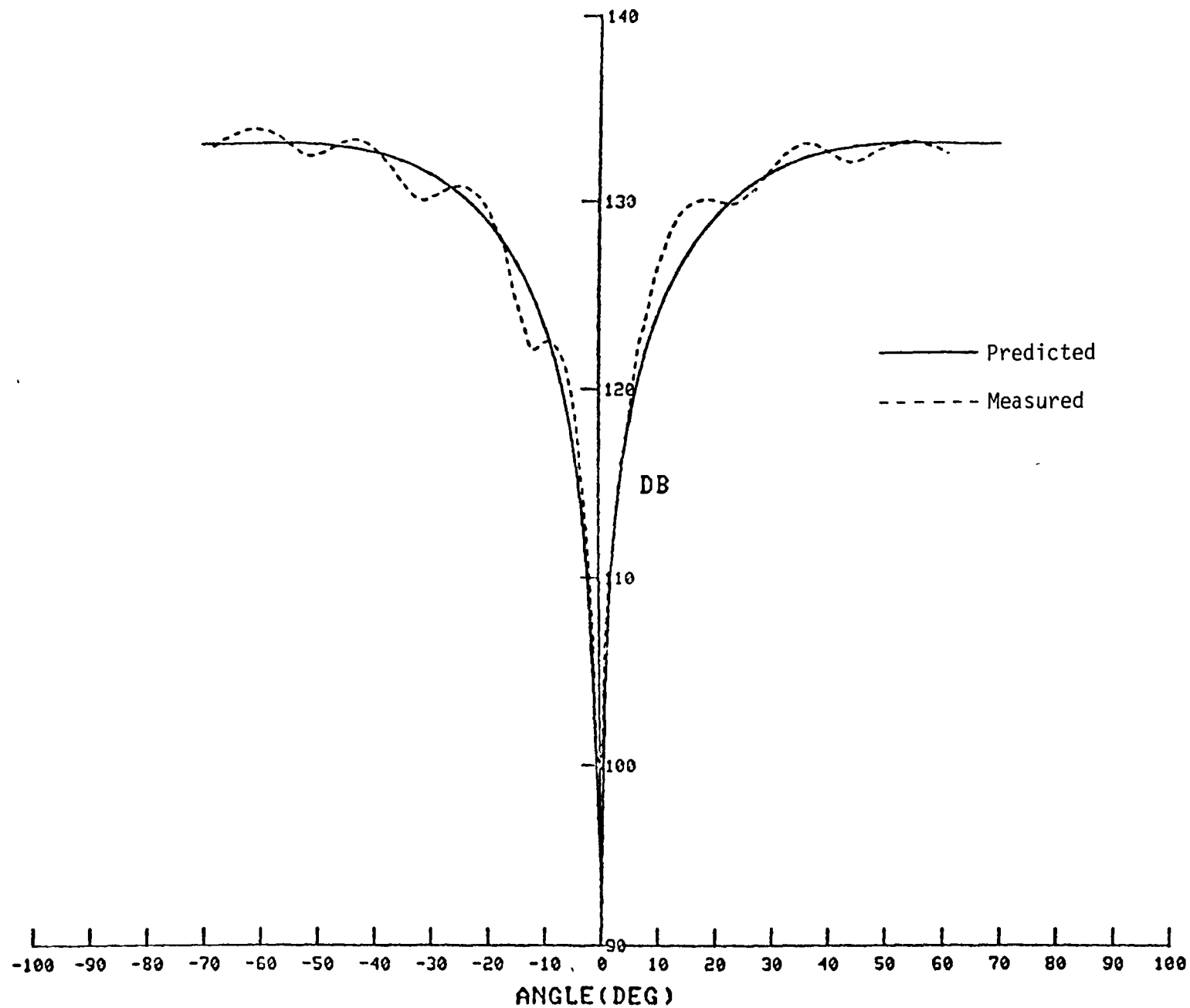
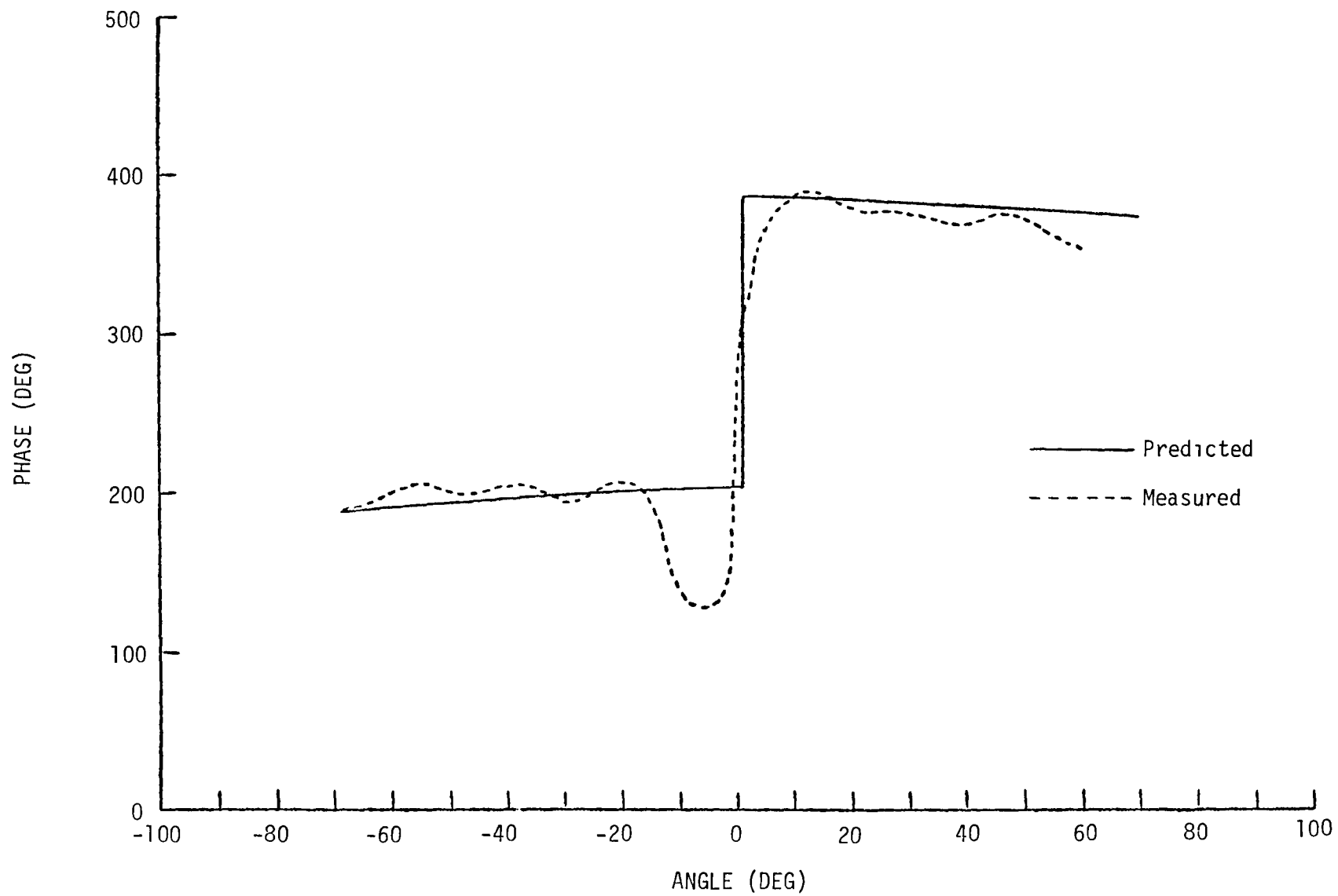


Figure 5.- Sound pressure level of radiated field from circular cylinder with plane baffle versus polar angle for (8,0) mode incident and frequency 4256 Hz



(a) Pressure level of radiated field

Figure 6.- Sound pressure level and phase of radiated field from 70° hyperboloidal inlet duct versus polar angle for (1,0) mode incident and frequency 960 Hz



(b) Phase of radiated field

Figure 6.- Concluded

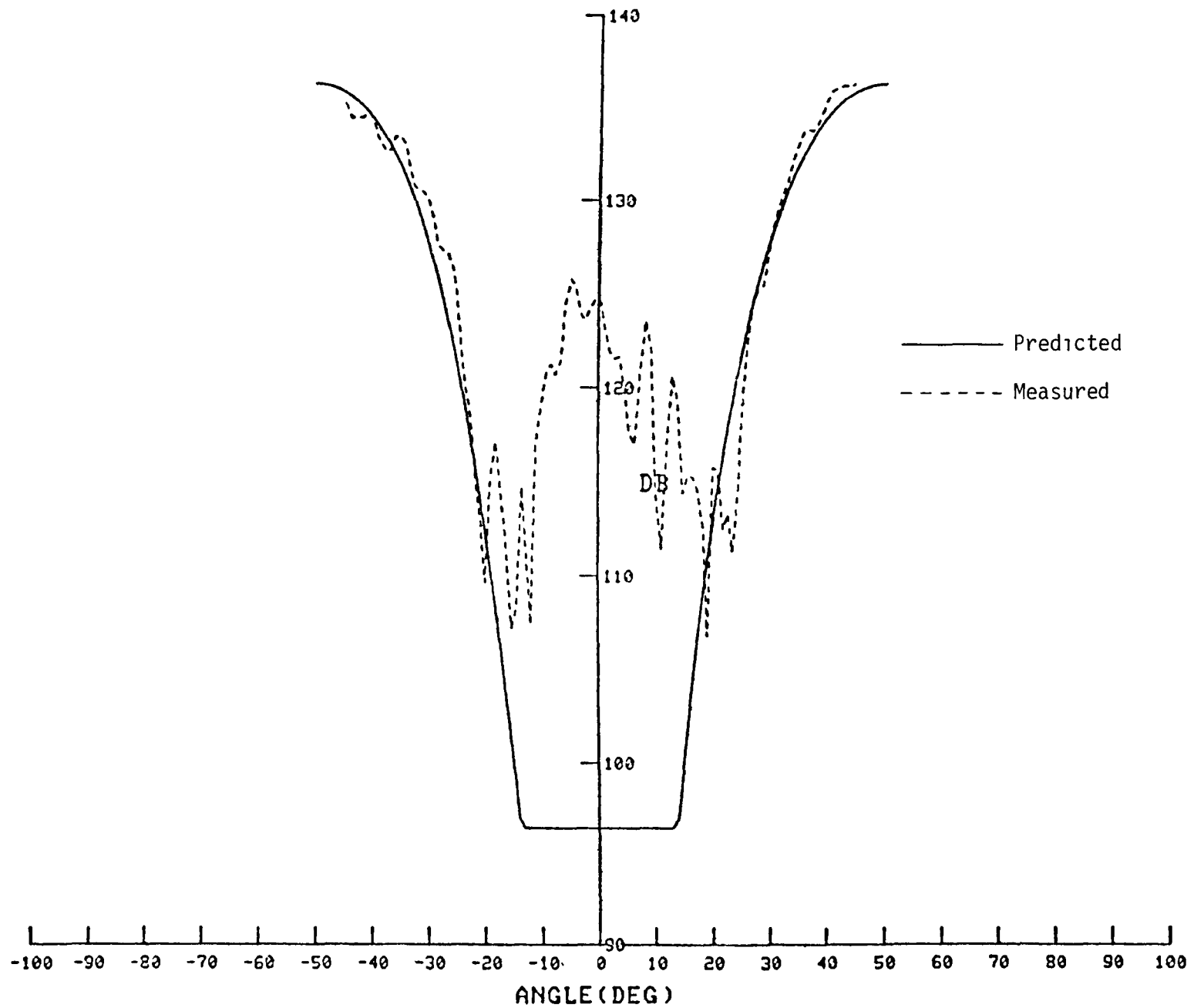


Figure 7.- Sound pressure level of radiated field from 50° hyperboloidal inlet duct versus polar angle for (6,0) mode incident and frequency 3312 Hz

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